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Optical and UV Light Curves of the Accretion Disk Corona Source 4U 1822-371

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Abstract. The eclipsing low-mass X-ray binary 4U 1822-371 is the prototypical accretion disk corona (ADC) system. We have obtained new time-resolved UV spectrograms of 4U 1822-371 with the Hubble Space Telescope and new V- and J-band light curves with the 1.3-m SMARTS telescope at CTIO. We present an updated ephemeris for the times of the optical/UV eclipses. Model light curves do not give acceptable fits to the UV eclipses unless the models include an optically-thick ADC.

1. Introduction

An accretion disk corona in a low-mass X-ray binary (LXMB) is material above and below the accretion disk that emits hard X-rays. It is believed that there is an ADC in most, if not all, LMXBs, but the ADC is invisible in most systems because the neutron star and inner disk are much more luminous. The ADC is visible in LMXBs with nearly edge-on orbital inclinations so that the X-ray flux from the neutron star and central disk are blocked by other parts of the disk further out from the center (White & Holt 1982). Because systems in which the ADC is visible have high inclinations, the accretion disk and ADC are eclipsed by the secondary star. The eclipse light curve yields information about the geometry and spectral energy distribution of the ADC.

4U 1822-371 is the prototypical ADC system (Mason et al. 1980). The existence of the ADC in 4U 1822-371 was deduced from the partial X-ray eclipse, which has two notable properties: (1) it has a gradual ingress and egress and is relatively shallow, with 50% of the flux remaining at mid-eclipse, and (2) it is wide, typically lasting $\Delta\phi = 0.1$ in orbital phase at X-ray wavelengths and double that at optical wavelengths (Hellier et al. 1990). White et al. (1981) showed that the X-ray emitting region must be vertically extended and comparable in size to the secondary star to produce the observed X-ray eclipse. The ADC is optically thick at X-ray wavelengths.

2. Observations

The new observations of 4U 1822-371 consist of time-series UV spectrophotometry obtained in 2006 with the Hubble Space Telescope using an objective prism on the ACS/SBC (Pavlovsky et al. 2006). The spectrograms have a usable wavelength range from 1222 Å to 1900 Å. The mean

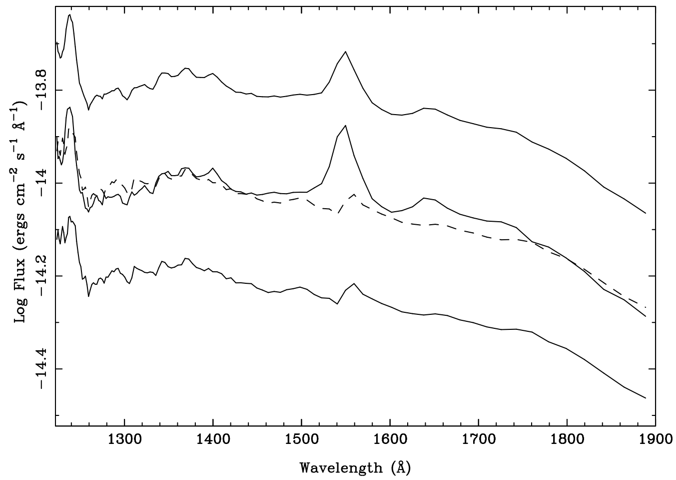

Figure 1. The UV spectrum of 4U 1822-371. The top line is the mean spectrum, the middle solid line is the spectrum for orbital phases within ±0.05 of mid-eclipse, the bottom line is the eclipse spectrum subtracted from the average spectrum, and the middle dashed line is the subtracted spectrum shifted up to the eclipse spectrum. The N V emission line at 1240 Å is mostly eclipsed, while the C IV 1550 Å and He II 1640 Å line are mostly not eclipsed.

spectrum, shown in Figure 1, has prominent emission lines of N V at 1240 Å, a blend of O IV, O V, and Si IV near 1370 Å, C IV at 1550 Å, and He II at 1640 Å. There are also ISM absorption blends of Si II and C I near 1260 Å, and of O I and Si III near 1300 Å. We formed an eclipse spectrum by averaging all spectrograms near mid-eclipse, and then a spectrum of the eclipsed flux by subtracting the eclipse spectrum from the mean spectrum (Figure 1). The N V line is mostly eclipsed while the C IV and He II lines are not. The C IV and He II emission must come from far above and below the disk.

The optical observations of 4U 1822-371 were taken in the V- and J-bands with ANDICAM on the SMARTS 1.3-m telescope at CTIO (DePoy et al. 2003). The observations consisted one or two measurements per night during 30 June - 15 September 2005 and 29 March - 20 October 2006.

3. Data Analysis

The UV spectrophotometry yielded two complete eclipse light curves. Because of the sparse sampling, the V- and J-band data were folded at the orbital period to produce mean light curves for the two observing seasons. Joining the new eclipse times to published times for the optical/UV eclipses, we find the following ephemeris for the times of minimum of the optical/UV eclipses

$$T_{min} = \mathrm{HJD}\ 2445615.31166(74) + 0.232108641(80)E + 2.46(21) \times 10^{-11}E^2,$$

where E is the cycle number. The left panel of Figure 2 shows the UV, V, and J light curves phase folded on this ephemeris.

We modeled the eclipse light curve from orbital phase -0.2 to 0.2, constraining the inclinations to $i > 80^\circ$ because the neutron star is hidden from view. We attempted to fit the eclipse with a wide variety of disk models without success. These models included flat disks with uniform surface brightness, flared disks, flared disks with a vertically-extended

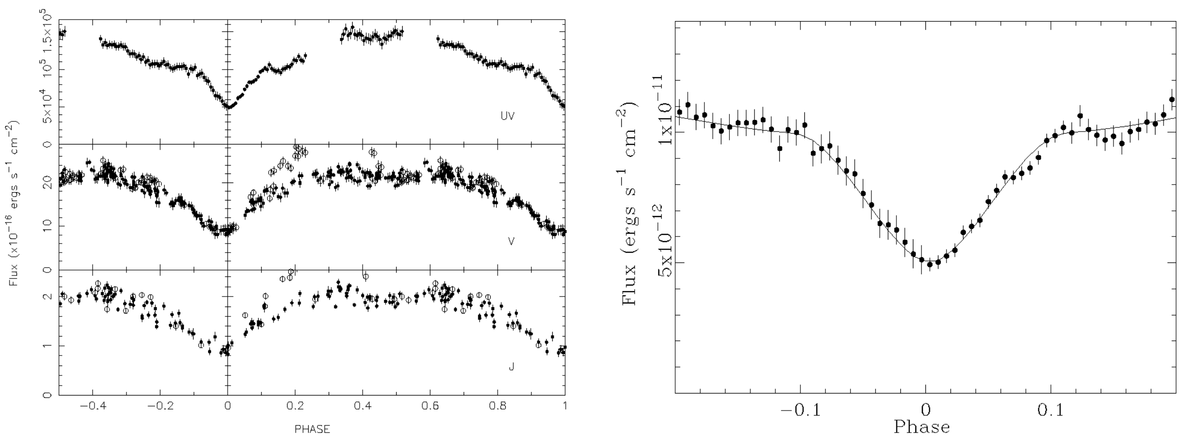

Figure 2. *Left Panel:* The mean light curve for the integrated UV flux, and the folded V- and J-band light curves. The open circles are from 2005 and the solid circles from 2006. *Right Panel:* The UV eclipse light curve. The points are the observed light curve and the solid line is the light curve produced by a model with an optically thick toroidal ADC.

rims, alpha-model disks, and all of these with irradiation. A few models failed because they gave light curves with clearly incorrect shapes, but most of the models failed in one of two generic ways: the eclipse light curves were too deep because the center of the disk was producing too much flux, or they required an inclination less than 80°. To remedy these defects we added a quasi-toroidal ADC. The ADC must be optically thick and vertically extended to block flux from the neutron star and inner disk. The right panel of Figure 2 shows the best fitting model light curve. In this model the orbital inclination is $i = 83.5°$ and the ADC extends out to $\sim 1/2$ the disk radius and has a maximum height also $\sim 1/2$ the disk radius.

4. Conclusion

To obtain acceptable fits to the UV eclipse light curve of 4U 1822-371 it was necessary to include an optically thick ADC in the light curve models. The ADC is large, with a radius and height equal $\sim 1/2$ the disk radius. Most of the light blocked during mid-eclipse in these models comes from the ADC, so the subtracted spectrum shown in Figure 1 is the UV spectrum of the ADC. The spectrum is not greatly different from the average spectrum of the system exception that the C IV and He II emission lines are nearly uneclipsed.

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